The importance of Bristol Bay salmon in North Pacific Ocean ecosystems

Authors: Sarah Gaichas and Kerim Aydin, Resource Ecology and Ecosystem Modeling Program, NOAA NMFS Alaska Fisheries Science Center, Seattle, WA

Summary: We evaluate the role of sockeye salmon from the Nushagak and Kvichak River systems in the Bering Sea continental shelf and oceanic North Pacific ecosystems from a food web perspective. We find that Bristol Bay sockeye salmon are important forage fish on the eastern Bering Sea (EBS) continental shelf during their first summer at sea, especially for Endangered Steller sea lions and protected northern fur seals. Fish from these two rivers comprise more than a quarter of total sockeye salmon biomass, and 12% of total salmon biomass in the oceanic north Pacific during the ocean phase of their life cycle. The ocean phase of salmon life history remains data poor relative to the freshwater phase, so quantitative prediction of impacts to ocean food webs from greatly diminished Bristol Bay salmon runs is difficult. Despite our lack of knowledge about key oceanic interactions for salmon and the resulting uncertainty over impacts to marine ecosystems, the disproportionately large contribution of these rivers to overall salmon biomass suggests their importance to North Pacific ecosystems.

Background
All Bristol Bay sockeye salmon smolts leave freshwater during late spring and spend their first summer foraging and growing rapidly on the southeastern Bering sea continental shelf (Burgner 1991, Farley et al 2005). Juvenile salmon are thought to suffer 90% of their total smolt-to-adult mortality during their first four months at sea (Furnell and Brett 1986, Pearcy 1992), which is when they are in residence on the EBS shelf. In the fall and winter, juvenile Bristol Bay sockeye salmon migrate off the EBS shelf and into the oceanic regions of the North Pacific both north and south of the Aleutian Islands; eventually occupying the subarctic domain in the oceanic North Pacific during winter (Burgner 1991). Over the next two to three years, Bristol Bay sockeye salmon migrate between wintering grounds in the subarctic gyres and summer feeding grounds in the oceanic Bering Sea (Myers et al 2007, Fig 4). West of 175°W they mix with the far less abundant Asian sockeye salmon, but they are distributed mostly east of 180°W in the eastern subarctic gyre (Myers et al 1996, Myers et al 2007). Maturing sockeye salmon return to Bristol Bay and their natal rivers during spring and early summer. Nearly half (48%) of maturing sockeye salmon tagged at sea in the North Pacific and recovered in natal river systems between 1956 and 1995 returned to Bristol Bay (Myers et al 1996).

Methods
Using Phil North's estimate of 1.6 billion smolts entering North Pacific ecosystems from the Nushagak and Kvichak/Naknek rivers annually[1], we applied upper and lower potential average weights for these individual smolts to estimate their total biomass density and compare them with the density of other forage fishes currently estimated to occupy the Bering Sea shelf. Measurements of juvenile sockeye salmon weights during their first summer on the Bering Sea shelf ranged from a low mean of 0.047 kg to a high of 0.135 kg between 2000 and 2003 (Farley et al. 2007). We used a weighted mean of age 1.0 and 2.0 weights assuming a 7:3 ratio of these ages based on the smolt counts in the Kvichak river for 2001 (Crawford 2001), and on forecasts for 2010 (Baker et al 2009), resulting in an average smolt weight of 0.075 kg on the EBS shelf. In subsequent years at sea, we used the approximate January weights reported in Aydin (2000), derived from Ishida et al. (1998): 0.35 kg, 0.9, and 1.5 kg for ocean age .1, .2, and .3, respectively. A smolt-to-adult mortality rate of 2.78 (corresponding to 6.2% survival; Bradford, 1995) was applied to the original number of smolts over 3 winters at sea to estimate total numbers at sea from

---

[1] In an email dated January 12, 2010, Phil outlines the methods for generating this estimate. We used this smolt number which is based on the reported ADF&G estimate of 10% egg-to-smolt survival, and an alternative outgoing smolt number of 457 million based on 2.8% survival (closer to Bradford's (1995) sockeye egg-to-smolt mortality rate of 3.9, or 2% survival) which results in returns of approximately 28 million adults using Bradford's (1995) sockeye smolt-to-adult mortality rate of 2.78.

multiple brood years: 90% of this mortality rate prior to the first winter to represent shelf mortality, then 5% each following year (55% of forecast returns for 2010 spent 3 years at sea; Baker et al 2009). Phil North's estimate of 28 million returning adults (assumed to average 2.0 kg each) was used for comparison with total adult salmon density on the EBS shelf.

Two occupied areas were used to estimate density in the EBS and oceanic North Pacific ecosystems: the southernmost half of the Bering Sea shelf including Bristol Bay (247,606.5 km^2), and the entire area of the eastern subarctic gyre (3,622,000 km^2). Density is estimated as N smolts * average weight of a smolt / area of ecosystem. We used both tons (t) and density in t/km^2 for comparison with ecosystem estimates for other salmon, commercial, and forage species reported for the EBS in Aydin et al. (2007) and for the oceanic North Pacific in Aydin et al (2003). Finally, we reviewed salmon's importance in diets of specific predators where data were available.

Results and Discussion
On the EBS shelf, Nushagak and Kvichak river sockeye salmon represent the majority of juvenile and returning adult salmon biomass according to our calculations. Assuming returns of 28 million adults weighing 2 kg each, these two rivers account for nearly 70% (56,000 of 81,100 t reported in Aydin et al 2007) of returning adult salmon biomass in the EBS. Depending on the numbers of smolts assumed and the weight of an individual smolt, which varies with the number of years in freshwater and environmental conditions in both freshwater and on the EBS shelf, juvenile sockeye salmon from these two river systems may rank among the top ten forage groups (Table 1). When compared with only single species/stock groups, they rank between fifth and seventh in importance, comparable to Pacific herring or eulachon. In the open ocean, sockeye salmon represent 47% of total estimated salmon biomass present in the eastern subtropical gyre (Aydin et al. 2003). According to our calculations using the lower number of entering smolts, Bristol Bay sockeye salmon from the Nushagak and Kvichak river systems comprise 26% of total sockeye salmon biomass, and 12% of total salmonid biomass in the entire eastern subarctic gyre (Table 2). Clearly these two rivers produce a significant portion of the salmon in offshore marine ecosystems, and the majority of salmon on the EBS shelf. Data on consumption of salmon by fish predators in these marine ecosystems is lacking at present;[2] however, available data suggest importance to marine mammal predators. The primary predators of salmon in the EBS shelf model are marine mammals, including pinnipeds and toothed whales (Aydin et al 2007).

Marine mammal diet data shows seasonal dependence on salmon. In a recent study of EBS northern fur seal diets, salmon rank second among fish in frequency of occurrence for animals on both Pribilof Islands from late July though September, 1990-2000 (Gudmundson et al. 2006, Fig 2). The Endangered western stock of Steller sea lions also rely on salmon during summer; salmon ranked second in frequency of occurrence in summer diets in all regions between 1990 and 1998 (Sinclair and Zeppelin 2002, Fig 4). These regions include the Bering Sea shelf and waters surrounding the Aleutian Islands, where salmon were noted to increase in diets during winter due to outmigrating juvenile Bristol Bay salmon (Sinclair and Zeppelin 2002, p. 981). There has been considerable concern regarding the amount and diversity of prey available for Steller sea lions and fur seals given their recent population declines (e.g., Merrick et al 1997, Atkinson et al. 2008), so diminished Bristol Bay salmon runs, which account for the majority of EBS salmon, would certainly add to this concern. Despite uncertainties regarding many food web links, the disproportionate contribution of Nushagak and Kvichak river sockeye salmon to the EBS and North Pacific marine ecosystems suggests that loss of these runs could have significant effects.

---

[2] In the published EBS shelf food web model (Aydin et al 2007) the estimate of density for the "salmon outgoing" functional group (smolts of all species) was based on the estimated consumption demand by predators in the ecosystem. However, the timing of annual groundfish food habits sampling during May and June on the southern shelf means that outgoing salmon smolts are not yet on the EBS shelf and therefore will not be present in groundfish predator diets. Therefore, groundfish predation on salmon may be greatly underestimated by current sampling.

Table 1. Potential rank of Nushagak and Kvichak river juvenile sockeye salmon among Eastern Bering Sea (EBS) continental shelf forage groups from Aydin et al. 2007 (left columns). The first potential rank is among single species groups only, and the second is among all groups including those combining many species in density estimates. Assumed number of smolts, average weight, and area of shelf occupied are given for a range of Nushagak and Kvichak river juvenile sockeye salmon density estimates.

lm Ran	N mol	eig kg	Area km²	ensi /km	ng ec ra	Al o ar	EBS model forage groups	ensi /km
					1	1	Pollock	.486
					2	2	Pollock_Juv	.492
					3	3	ndlance	.527
					--	4	lpouts	.371
					4	5	pelin	.244
					--	6	sc. fish (shallow)	.167
					--	7	her managed forage	.050
					--	8	uids	0.9
or	5E+	0.1	7600	8723	--	9	yctophidae	.826
					5	0	rring	.611
or	5E+	0.0	7600	.484	6	1	lachon	.552
or	5E+	0.0	7600	8037	--	2	her pelagic smelt	.498

Region	smolt	weight kg	Area km²	Density /km	Age		N Pacific model salmon groups	Density /km
					7	4	Cod_Juv	.185
					8	5	rring_Juv	.171
					9	6	cific ocean perch	.166
					--	7	lmon returning	.163
					--	8	thylagidae	.161
or	6E+	0.0	7600	385	10	9	ka mackerel	.106
or	6E+	0.0	7600	.086	11	20	ka mackerel_Juv	.037
					12	21	rthern rockfish	.027
					--	22	lmon outgoing	0.01
					--	23	her Sebastes	.011
					13	24	blefish_Juv	.003
					14	25	sky rockfish	.000

Table 2. Contribution of Nushagak and Kvichak river sockeye salmon to total eastern N. Pacific salmon biomass as reported in Aydin et al. 2003 (Eastern Subarctic model; left columns).

3S	6E+	0.0	7600	1385	age .0	ckeye	.089
Pacif	7E+	0.	6220	.003	age .1	um	.054
Pacif	3E+	(	6220	0081	age .2	nk	.023
Pacif	8E+		6220	.011	age .3	ho	.004
						inook	0.00
tal N. Pacific				0234		elhead	0.00
				2.35	all salmonid		
				6.18	sockeye		

References

Atkinson, S, D.P. DeMaster, and D.G. Calkins. 2008. Anthropogenic causes of the western Steller sea lion Eumetopias jubatus population decline and their threat to recovery. Mammal Review 38(1):1-18.

Aydin, K. 2000.

Aydin, K., S. Gaichas, I. Ortiz, D. Kinzey, and N. Friday. 2007. A comparison of the Bering Sea, Gulf of Alaska, and Aleutian Islands large marine ecosystems through food web modeling. US Department of Commerce, Washington D.C. NOAA Tech. Memo. NMFS-AFSC-178.

Aydin et al 2003

Baker, T., F. West, and G. Buck. 2009. 2010 Bristol Bay sockeye salmon forecast. Alaska Department of Fish and Game, Anchorage AK. Downloaded March 1, 2010 from http://www.cf.adfg.state.ak.us/region2/finfish/salmon/bbay/brbfor10.pdf

Bradford, M.J. 1995. Comparative review of Pacific salmon survival rates. Can. J. Fish. Aquat. Sci. 52: 1327-1338.

Burgner 1991

Crawford, D.L. 2001. Bristol Bay sockeye salmon smolt studies for 2001. Alaska Department of Fish and Game Reional Informaiton Report no. 2A01-27. Anchorage, AK.

Farley et al 2005

Farley et al. 2007

Furnell and Brett 1986

Gudmundson et al. 2006

Ishida et al. 1998

Merrick et al 1997

Myers et al 1996

Myers et al 2007

Pearcy 1992

Sinclair and Zeppelin 2002